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ABSTRACT

This booklet from the Energy Research and Development Administration presents a plan for the energy research development and dissemination activities of the Federal government. The discussions highlight present and proposed energy RD&D efforts and mention areas of needed research. Chapter titles, which indicate contents, are: (1) Understanding conservation; (2) Reviewing the conservation technology base; (3) Technologies that expand existing fuel sources; (4) Technologies that use new fuels; (5) Development of support technologies; (6) On-going program planning studies; and (7) Overview of ERDA's budget. This RD&D plan was designed to be in consonance with the President's National Energy Plan. This document could be of interest to those studying energy policy formulation.

(MR)

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A National Plan for Energy Research, Development and Demonstration

Energy Research and Development Administration

ERDA 77-1

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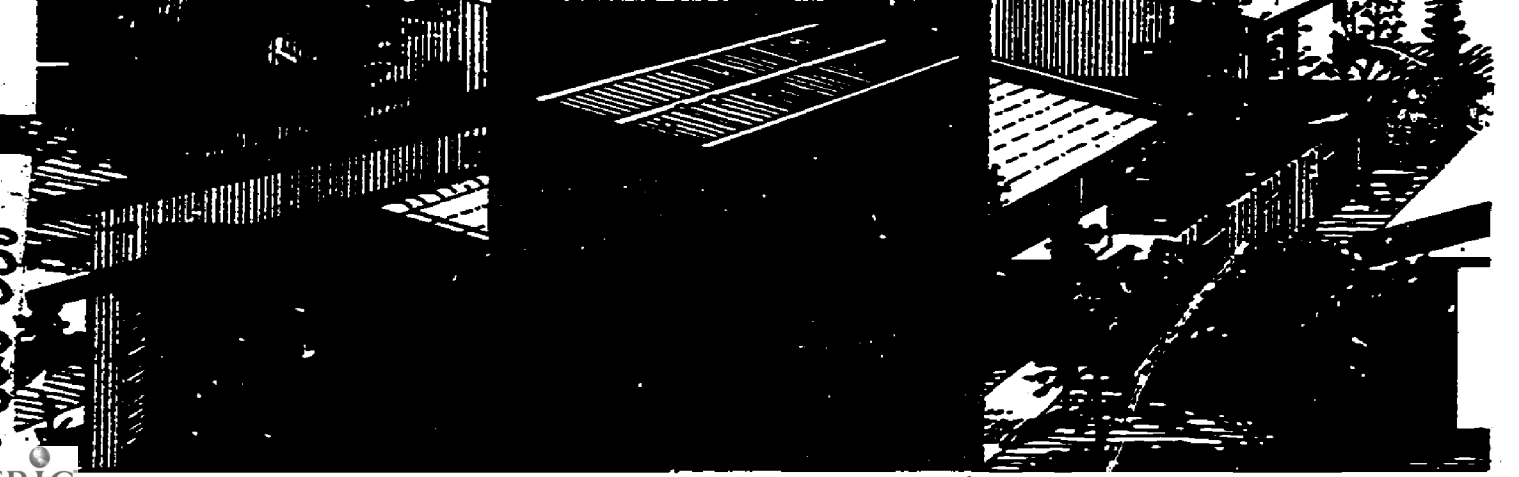
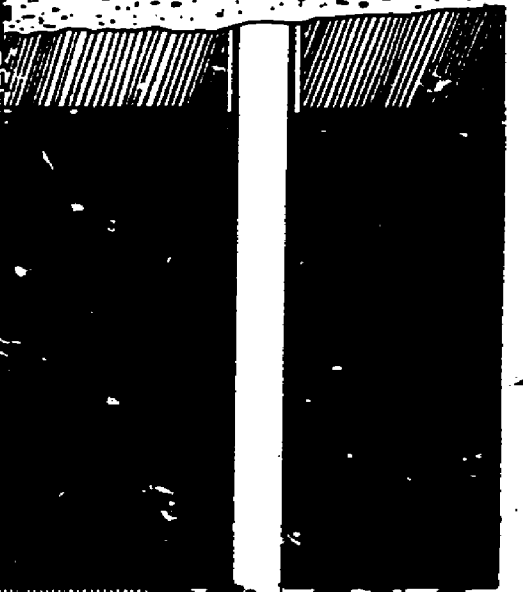
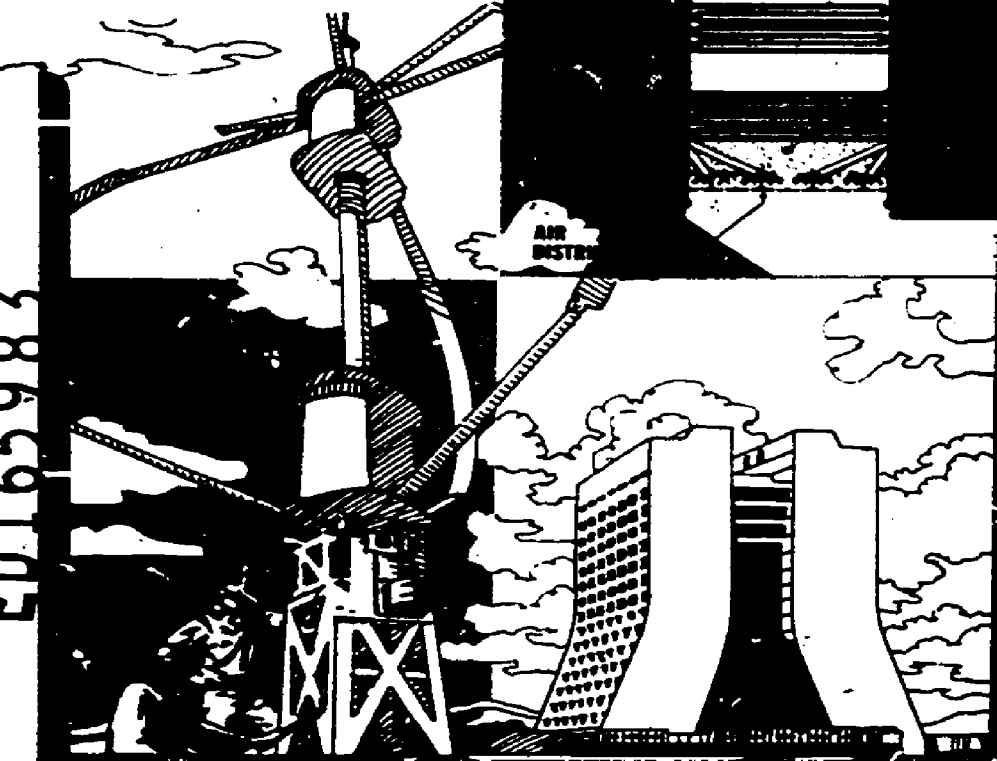
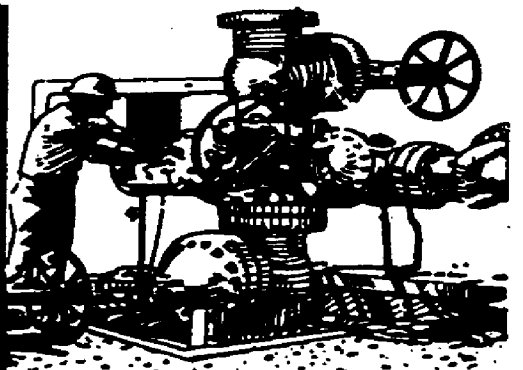
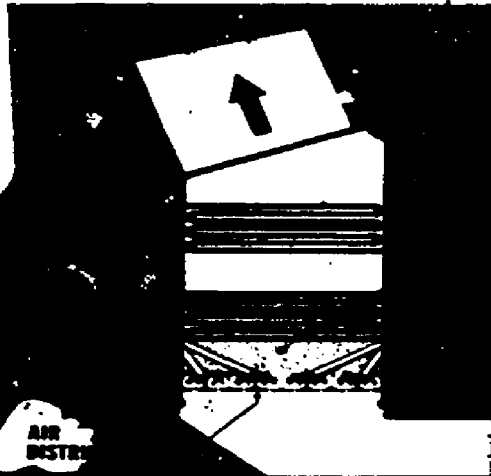
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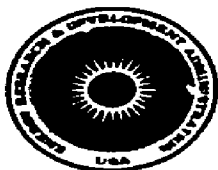
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UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

June 23, 1977

The President of the United States
The President of the Senate
The Speaker of the House of Representatives

Sirs:

I enclose for your consideration ERDA 77-1, "A National Plan for Energy Research, Development and Demonstration." This report was prepared in response to Section 15 of the Federal Nonnuclear Energy Research and Development Act of 1974, which requires ERDA to develop a comprehensive plan for energy research, development, and demonstration.

The RD&D program described in the enclosed report is in consonance with and supports the President's National Energy Plan, submitted to the Congress on April 20, 1977. The President's overall energy plan provides the needed context for the national energy RD&D effort and includes specific sections on energy RD&D. ERDA's activities in this area, combined with those of other federal agencies involved in energy RD&D, can provide the basis for the technological change needed to allow the U.S. to weather the period when world oil production approaches its capacity limitations, and to transition to renewable or essentially inexhaustible sources of energy for the future.

Sincerely,

A handwritten signature in dark ink, appearing to read "Robert W. Fri", is written over the typed name.

Robert W. Fri
Acting Administrator

A National Plan For Energy Research, Development and Demonstration

ERDA 77-1

**Energy Research and
Development Administration
June 1977**

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INTRODUCTION

In accordance with Section 15 of the Federal Nonnuclear Energy Research and Development Act of 1974 (Public Law 93-577), this report presents a discussion of the energy research, development and demonstration (RD&D) program currently being conducted by the Energy Research and Development Administration (ERDA). The RD&D program is in consonance with the President's National Energy Plan, submitted to the Congress on April 20, 1977.

The energy problem has been clearly stated in the National Energy Plan as follows:

"The diagnosis of the U.S. energy crisis is quite simple: demand for energy is increasing, while supplies of oil and natural gas are diminishing. Unless the U.S. makes a timely adjustment before world oil becomes very scarce and very expensive in the 1980's, the nation's economic security and the American way of life will be gravely endangered. The steps the U.S. must take now are small compared to the drastic measures that will be needed if the U.S. does nothing until it is too late."

Moreover, the Plan has been conceived to meet the following three overriding objectives:

"...as an immediate objective that will become even more important in the future, to reduce dependence on foreign oil and vulnerability to supply interruptions;

...in the medium term, to keep U.S. imports sufficiently low to weather the period when world oil production approaches its capacity limitation; and

...in the long term, to have renewable and essentially inexhaustible sources of energy for sustained economic growth."

The strategy of the Plan contains three major components to achieve these objectives:

First, by carrying out an effective conservation program in all sectors of energy use, through reform of utility rate structures, and by making energy prices reflect true replacement costs, the nation should reduce the annual rate of growth of demand to less than 2 percent. That reduction would help achieve both the immediate and the medium-term goals. It would reduce vulnerability and prepare the nation's stock of capital goods for the time when world oil production will approach capacity limitations.

Second, industries and utilities using oil and natural gas should convert to coal and other abundant fuels. Substitution of other fuels for oil and gas would reduce imports and make gas more widely available for household use. An effective conversion program would thus contribute to meeting both the immediate and the medium-term goals.

Third, the nation should pursue a vigorous research and development program to provide renewable and other resources to meet U.S. energy needs in the next century. The Federal Government should support a variety of energy alternatives in their early stages, and continue support through the development and demonstration stage for technologies that are technically, economically, and environmentally most promising.

This National Energy Plan is necessary because, despite positive efforts by federal and state governments, industry, and the American public to conserve energy and to increase domestic energy supplies, the Nation is, more than ever, most reliant on the least plentiful domestic energy resources, petroleum and natural gas. Moreover, the Nation cannot solve this problem simply by increasing the level of energy imports, because much the same situation exists worldwide.

Natural gas must be liquefied for ocean transport. Due to its high costs and possible safety problems imported liquefied natural gas (LNG) is not a long-term, secure substitute for domestic natural gas. It can, however, be an important supply option through the mid-1980's and beyond, until additional domestic gas supplies may become available. The Nation will continue to depend primarily on domestic resources of natural gas.

To do so, additional quantities of this fuel must be made available through expanded exploration, the development of supplemental sources, and more efficient means of extraction. Moreover, to stretch available quantities of this finite and nonrenewable resource, the Nation must curb domestic demand for this fuel through conservation measures and by replacement by other, more abundant or renewable domestic energy resources.

Unlike natural gas, petroleum can readily be transported in large quantities across oceans. However, the global petroleum situation closely parallels the domestic situation. The world is running out of cheap and easily expandable reserves of petroleum, and continued dependence on imports for a

substantial portion of total energy needs cannot be sustained during the latter part of this century because world production cannot keep pace with even conservative estimates of world demand growth and because the financial and economic costs would be immense.

Figure I shows the current and ERDA projected cumulative world production of petroleum. As standards of living increase throughout the world, the demand for petroleum will probably fall between the historical annual growth rate of 6 to 8 percent and the 0-percent annual growth that could be attained by aggressive conservation measures in all industrialized nations and by restrained energy-demand growth in less developed countries. But regardless of which rate is assumed, the world cumulative production of petroleum would exhaust one-half the world's petroleum resources some time around the end of the century. Then, the peak annual production of the resource will be reached, and annual production will begin to decline. In actuality, because of political and other considerations, peak production could occur much earlier¹, but whenever it occurs, declining production will put additional upward pressure on petroleum prices and on international tensions among nations.

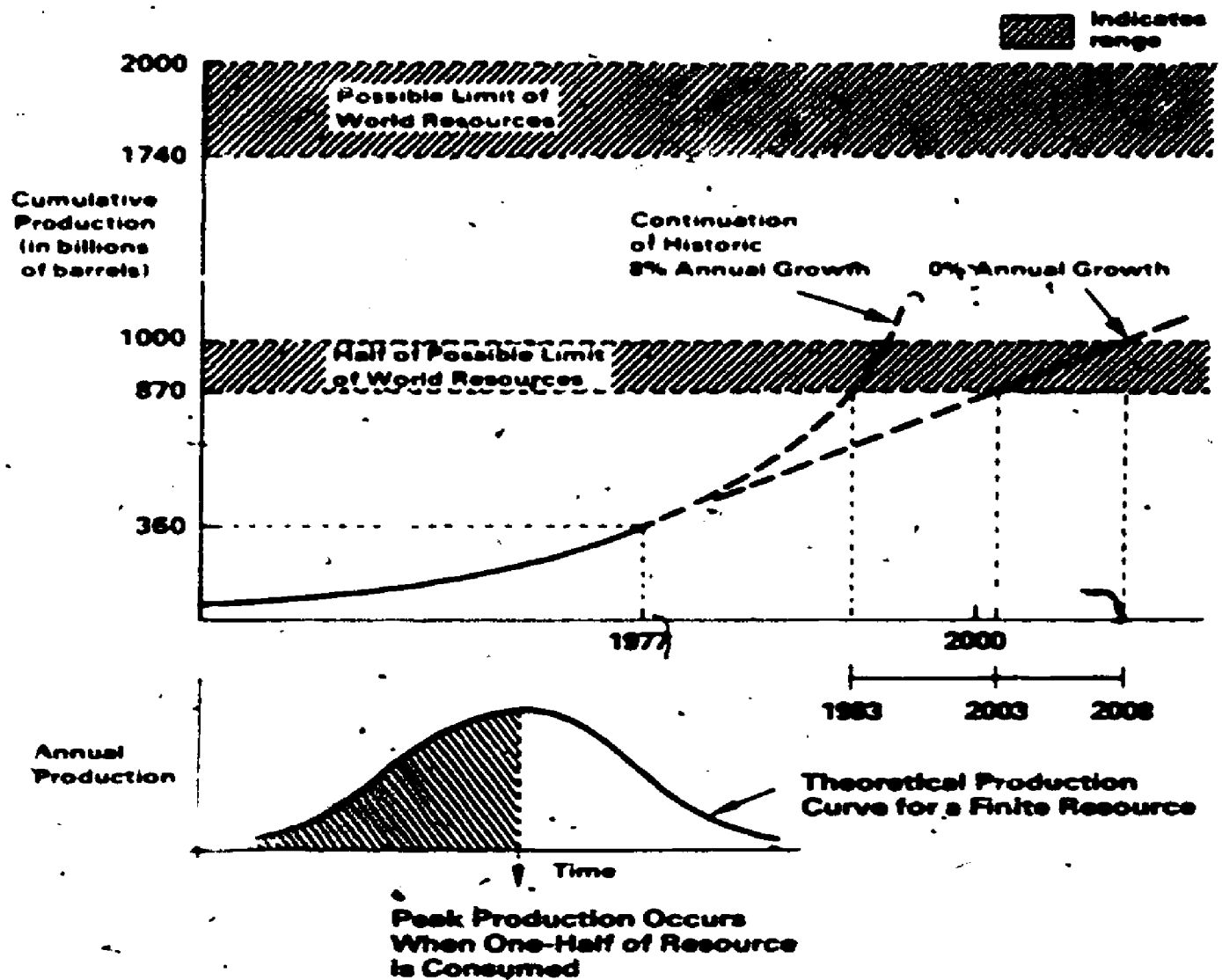
As an illustration, Figure II shows the rapidly increasing gap between growing world petroleum demand and declining world petroleum production, based on a theoretical curve for a finite resource and the production required by a three-percent annual growth rate, which current international studies indicate as a difficult but possible future rate. In reality, the gap will not exist, and production will equal demand. **But this balance between production and demand will be achieved through increased world prices for petroleum, which will increase production and decrease demand.** At the same time, increased international tensions will occur as nations compete more intensively for the ever-decreasing quantities of petroleum produced.

The implications of this analysis are clear: it is not enough to be concerned about import levels; the Nation must be concerned about **total consumption** levels of petroleum and natural gas over time. That is, it is not percentage levels of petroleum or energy use that must be of concern, but absolute levels of use. At some point the Nation must stop the rising level of absolute use of these fuels from present sources and achieve a continually decreasing pattern of use by about the end of the century.

The transition from consumption of petroleum and natural gas to use of more abundant fuels will be more difficult than previous transitions. The reasons for moving to other energy sources at this time are very different from those that precipitated such action in the past. Specifically, previous transitions (e.g., from coal to petroleum and natural gas) occurred because the new fuel was more economical, or more environmentally acceptable, or easier to transport or distribute than the previously used fuels. Moreover, while the

¹ See, for example, *The International Energy Situation: Outlook to 1985*, ER 77-1024OU; Central Intelligence Agency (CIA), April 1977.

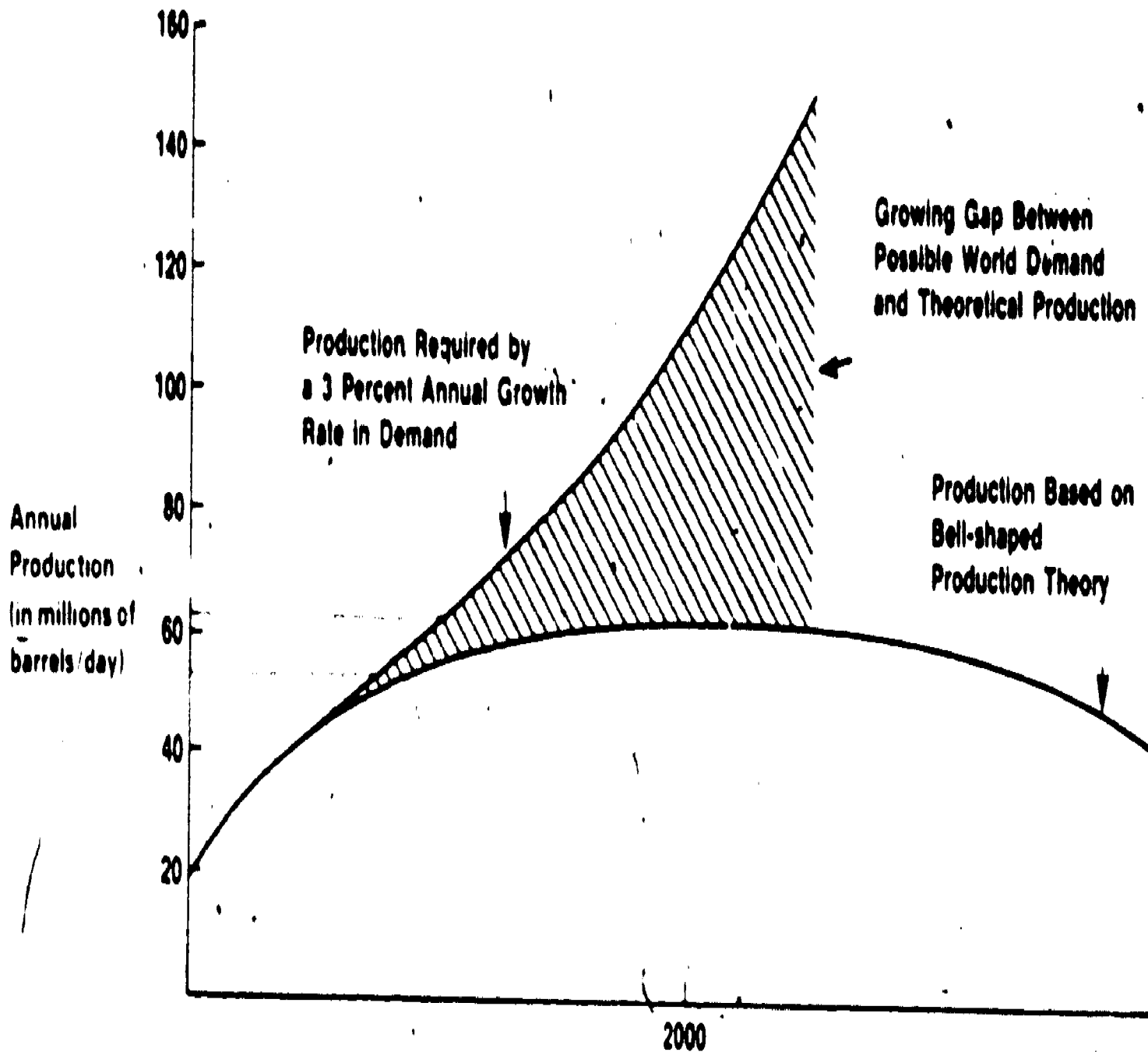
Figure 1
Current and Projected World
Production of Petroleum*



* Includes crude oil and natural gas liquids.

Figure 11

Projected World Petroleum* Consumption as Limited by Future Petroleum Production Decline



* Includes crude oil and natural gas liquids.

transition took place, there were continuing supplies of all fuels at reasonable prices.

Increases in petroleum and natural gas prices will make energy alternatives more attractive, but, without a comprehensive National Energy Plan, normal market forces will not spur the transition to other fuels rapidly enough to avoid excessive costs to the Nation in terms of economics, environment, national security, and lifestyle changes. Thus, it is clear that the Nation cannot afford to wait decades to complete the next transition. (See Figure III for the time phasing of historical transitions from wood to coal and from coal to oil and gas). The next transition must be well under way by the end of this century, and it must be initiated today.

To help solve the Nation's energy problem and to meet the three national energy objectives, new technology must be developed to **(1) increase the efficiency of energy use, (2) expand the use of existing fuels, and (3) make the transition to new fuels.** This report presents ERDA's effort in these three areas.

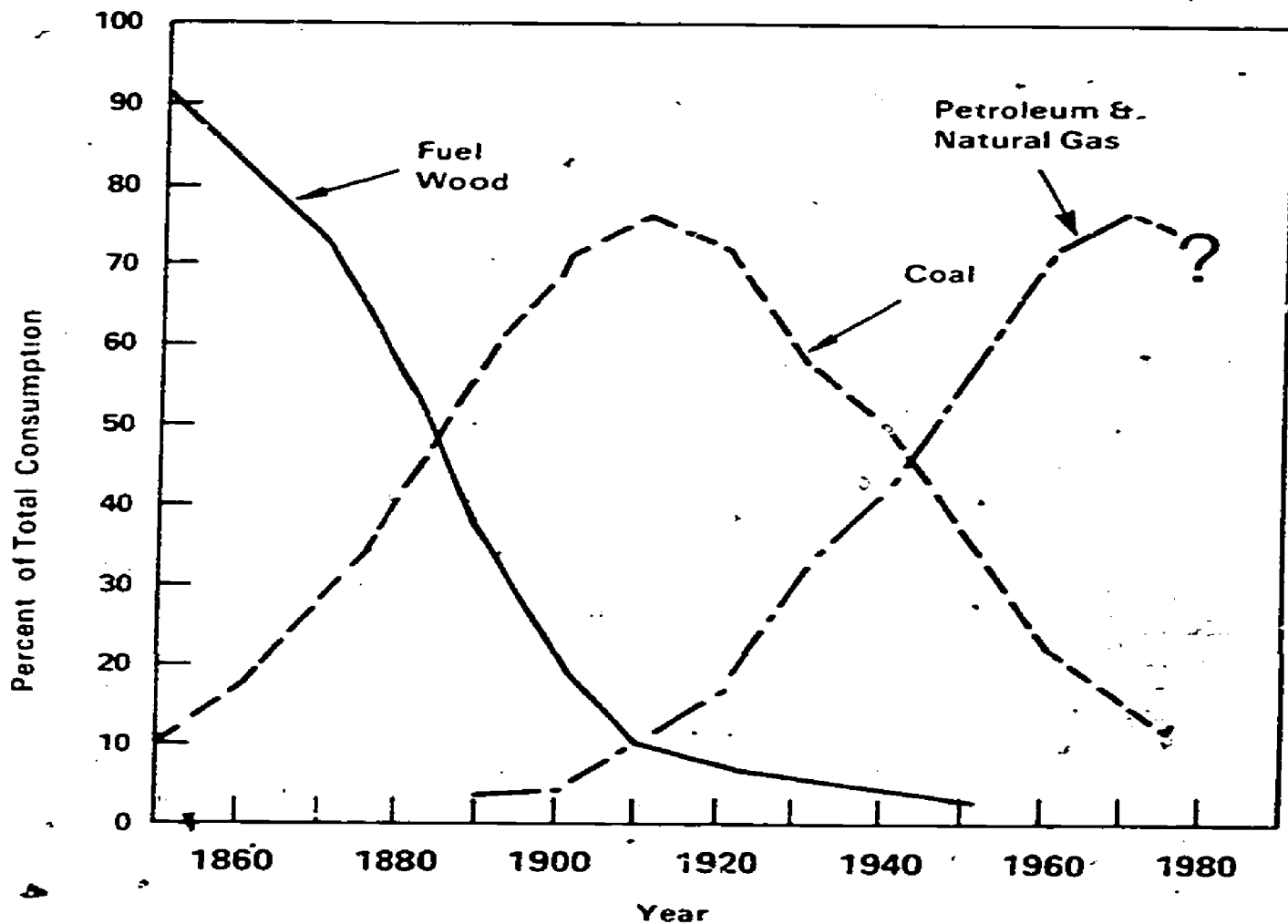
In general, increasing the efficiency of energy use (conservation) can have the greatest immediate impact on the Nation's energy system between now and 2000. This impact can be obtained through a coordinated set of actions involving voluntary efforts, economic incentives, regulatory actions, and development of more efficient technologies to use and produce energy.

The expansion in the production and use of existing fuels (such as oil and natural gas, coal, and uranium, using a once-through fuel cycle in light water reactors) can also provide a substantial contribution to solving the Nation's energy problem between now and 2000. The expansion of existing fuels combined with increases in energy efficiency will provide most of the impetus in meeting the Nation's energy goals in 1977-2000 period.

Due to the long development times for difficult new technologies (such as solar electric, hot dry rock geothermal, breeder concepts or fusion), their major energy contributions are expected to occur after the turn of the century. But, the research and development (R&D) needed must be pursued today if the potentials of these technologies are to be realized in time. Meanwhile, the new fuel technologies which are likely to be the significant pre-2000 contributors to energy supplies are solar heating and cooling, hydrothermal-geothermal, geopressured geothermal, biomass and shale oil. The combined contribution from these new fuel technologies is still likely to be smaller at the end of the century than from either conservation or existing fuel technologies at that time. However, new fuels will continue to grow in importance as the transition to renewable and essentially inexhaustible fuels continues into the 21st century. Prior to that time, energy contributions from these sources can and will ease the burden on existing depleting fuels and on imports, thus playing a key role in the energy transition process.

The RD&D development necessary to provide for the realization of the three technology thrusts discussed above (energy efficiency, existing, and new

Figure III
U.S. Energy Consumption Patterns
by Major Energy Source *



*Sources: "Historical Statistics of the United States,"
 Bureau of the Census; U.S. Bureau of Mines.

fuels) must be carried out by the Nation in an economically and environmentally acceptable manner. This in turn requires continued emphasis on supporting basic research and environmental technologies and in focusing the RD&D efforts toward the marketplace, these technologies will enter.

In view of these considerations, this report is divided into seven chapters:

- Understanding conservation
- Reviewing the conservation technology base
- Technologies that expand existing fuel sources
- Technologies that use new fuels
- Development of support technologies
- Ongoing program planning studies
- A final chapter presenting a Fiscal Year 1978 budget overview and the budget trends since the creation of ERDA in 1975.

Chapter 1

Understanding Conservation

"Energy conservation" is a term that has been widely used in the last few years, but it means different things to different people. To some it implies giving up or curtailing services and activities that require energy; to some it means using more efficient equipment and appliances; to some it means using more efficient methods of obtaining oil, gas, or coal from known reserves. In fact, energy conservation encompasses all of these, and more. It means not only reducing our consumption of energy, but also using energy more efficiently now and for the future, individually and collectively.

Three types of action are required to achieve national conservation of energy:

- **Promotion of an energy conservation ethic** to reduce the demand for energy. Consumers must understand the national security importance and the economic value of conservation as well as the need to reexamine the purposes and scale of use for services that depend on energy. Energy RD&D obviously has, at best, a peripheral role to play in this approach.
- **Conversion of facilities and equipment** to provide essentially the same energy services with less energy. Buildings, automobiles, and equipment of all kinds can usually be made more energy-efficient through modest investment. The addition of building insulation can conserve considerable amounts of energy presently used for space heating and cooling. Waste heat recuperators recycle energy that would otherwise be exhausted unproductively. More efficient automobile engines can dramatically reduce the consumption of gasoline. RD&D can make a major contribution to this approach, especially where the improvements require new technology rather than simply retrofitting established technologies and methods.
- **Development of new, energy-efficient methodologies and technologies** that conserve energy by using it more effectively or

by using more abundant or self-renewing sources of energy. This approach may involve sweeping changes in communications, manufacturing, and services; in the production or derivation of usable fuels; even in the lifestyle of the Nation. Substitution of rail mass transit for the automobile or telecommunications for travel could radically change urban patterns and the conduct of business. New processes for refining steel and aluminum and new techniques for enhanced oil recovery could have major impacts on industry. Such changes may depend heavily on the development and use of new technology.

All three approaches, to be effective, must be practiced continuously since conservation will always be a component of national energy policy. However, each approach has a different time frame. The first approach can be initiated quickly but the results may be short-lived unless a sustained effort is made. Experience shows that consumers frequently revert to former practices: the small-car market, which experienced a brief boom after the post-embargo gasoline shortages, has subsequently yielded ground to the medium-sized and large-car market. However, even limited responses buy time for the development of other energy options; and short-term actions may be the only options for crises, such as last winter's natural gas shortage.

Conversion of facilities and equipment takes longer to implement, but can achieve its full impact in a matter of years. These energy savings are permanent; for example, energy savings from building insulation save energy every year after installation. Substitution of more abundant fuels for petroleum or natural gas can be considered as part of this conservation approach. This substitution may be acceptable even though it involves an increased absolute British thermal unit (Btu) expenditure in the short-term, because it reduces the demand for the scarcer fuel. Again, this approach not only eliminates waste in energy use, but buys time for more comprehensive solutions.

The third approach, calling for major investments of capital, will realistically be implemented only as part of the normal capital-replacement cycle. Houses, factories, mines, railroads, and other large, permanent facilities and systems are not scrapped and replaced simply because a new technology or system becomes available; replacement will be considered only when they become economically obsolete. New, integrated energy-efficient systems, technologies, and facilities will take effect primarily in the longer term as they are installed in place of their obsolete, less efficient counterparts.

In effect, then, the first two approaches will have their most important impact in the near term by eliminating waste and by providing time for the pursuit of innovative solutions to energy problems. All three will play a role in the mid-term by reducing the need to expand the use of existing energy sources and the demand for new fuels as they become available.

And over the long term, energy conservation, especially major changes in energy-use patterns, can play a critical role in limiting the environmental

consequences of the growing worldwide use of energy. Conservation may not be the final answer to the environmental impacts of energy use, but it will, without question, reduce the problem to more manageable proportions.

Three methods of encouraging or enforcing these conservation actions are available: public persuasion, regulation, and creation of economic incentives.

Through education, advertising, and other channels of communication — public and private — all sectors of the society may be persuaded of the benefits to themselves and to the Nation of taking conservation action. This method can be applied by individuals, in both their social and professional roles, by organizations and institutions, and by all levels of government.

Regulatory measures to motivate conservation include standards requiring the use of energy-efficient systems, allocation or rationing of scarce fuels, and limitation of availability (e.g., brownouts). These methods can be applied by regulatory agencies at all levels of government.

Economic incentives and disincentives, such as favorable prices for energy-conserving equipment, fuel price controls, and special taxes and rebates favoring conservation practices, influence the behavior of the market, and therefore of the consumer, to encourage conservation and discourage excessive demands and waste. Economic incentives can emerge naturally but can also be augmented by legislative and regulatory action.

All three methods, singly or in combination, apply to all types of conservation action. For example, a householder may turn down a thermostat as the result of a Presidential message, or because of a mandated setting, or because of a rise in the price of fuel. However, the institution of economic incentives and disincentives is probably the most important and most effective means of encouraging long-term conservation.

A major investment of resources in an energy-efficient technology must be cost-effective; the trade-off between costs and benefits must be viable. An electric generating plant could consume less coal or oil if the maximum operating temperatures and pressures were increased; however this change could entail inordinately expensive construction and decreased reliability. Similarly, building insulation can be progressively increased to reduce heat loss, but eventually a point is reached where an increment in the energy savings is worth less than the cost of installing the insulation needed to achieve it.

Economic factors are therefore critical in approaches and investments. Decisionmakers must consciously balance the trade-offs between energy savings and capital, labor, and other costs in their planning. It is a great deal less costly to plan for insulation when designing a house than to add insulation after the house is built. Economically sound decisions made early enough in the process should save more energy than those made later.

The implementation of conservation approaches can also have positive effects on controlling fuel prices. Reduced demand for limited fuel supplies will tend to limit their prices. For all energy consumers, rich and poor alike, be

they individuals or nations, the combined effect of lower prices and lower quantities used will reduce the amount of income needed for energy services. Of course, this effect only delays the day of reckoning when the limited petroleum and natural gas resources are in fact depleted, but it provides time, which if used judiciously, can enable individuals and nations to find better ways of meeting their needs for energy services.

Chapter 2

Reviewing the Conservation Technology Base

RD&D plays a key role in conservation; this role can best be understood by examining the technological base for conservation in three end-use sectors: transportation, residential/commercial, and industrial. The number of individual technologies required for effective conservation in each of these sectors is large so the following discussion highlights only a few of the significant options.

Transportation Sector

The transportation sector embraces many different energy-consuming systems and accounted, in 1976, for 20 quads¹ (or 26 percent) of total domestic energy consumption. However, the passenger vehicle, accounting for more than nine quads of the total, is by far the largest energy user in the sector. Consequently, it is a prime target for conservation measures.

In the near term, conservation will be achieved through evolutionary modifications of existing types of vehicles, engines and components. Smaller, lighter cars with smaller engines (and less power per unit weight) will provide some of the mandated improvement in miles per gallon. Other easily adopted modifications to the present internal combustion engine, such as computer-controlled ignition and fuel/air ratio and lock-up torque converters, will contribute substantially to conservation — perhaps, eventually, as much as reductions in vehicle size and lowered performance.

Two alternative engine systems, the turbine and the Stirling, may offer significant advantages in meeting the national objective of improved fuel mileage and clean air. Both engines involve continuous combustion processes that reduce air pollutant emissions while improving fuel economy.

The turbine is further advanced than the Stirling engine, since the former has drawn heavily on aircraft jet engine technology. While there are difficult problems remaining in the development program, the turbine offers efficien-

¹ One quad is equal to 10^{15} Btu's.

cies of as much as 50 percent greater than those of conventional engines when ceramic components capable of withstanding the necessary high temperatures can be inexpensively produced. An infinitely variable transmission with a more conventional turbine offers an alternative approach.

The Stirling cycle has been limited in its applications mainly to fixed installations at near-constant loads. An automotive version has been under development for only a few years. To meet space, weight, and performance objectives, the automotive Stirling must operate at pressures of about 3,000 pounds per square inch, which are difficult to maintain. The heat exchanger must operate at high temperatures and very high pressure, while the piston rod seal must have very low leakage in a difficult environment. In addition, a control system that meets automotive requirements without reducing efficiency must be developed. Success in resolving these problems could improve fuel efficiency by 50-60 percent.

Neither of these systems could have a significant impact on conservation for more than 10 years. At least five years of development lie ahead before production and production-line engineering can begin in earnest. Even when an RD&D commitment to either or both of the new engines is made, production lines cannot be converted to the new system in less than a decade. However, if the new engines are successfully developed, they will add important savings to those achieved by other automotive improvements and act directly to further reduce the levels of petroleum consumption in that critical time period.

The development and introduction of electric and hybrid automobiles is also being pursued. These would provide a substitution capability for many gasoline and diesel-powered vehicles currently used in routine, short-haul, low-load applications and in commercial use in urban areas as well as rural areas. The Congress enacted the "Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976" (Public Law 94-413) to require (a) the demonstration of the technical and economic practicability of such vehicles, (b) the establishment of performance standards, and (c) the implementation of a loan guarantee program to encourage the commercial production of such vehicles.

Nonautomotive transportation — trucks, airplanes, railroads and ships — likewise shows a potential for significant energy savings by the year 2000. Some of these changes are dependent on major capital investments such as the purchase of new fleets of commercial aircraft in which improved energy efficiency is but one of several decision criteria.

Residential/Commercial Sector

The residential/commercial sector accounted, in 1976, for 37 percent of domestic energy consumption. Of this use, some 63 percent was for space conditioning. Because of the characteristically long life of buildings, conservation systems that can be retrofitted into the existing stock of buildings are

required as well as those that can be incorporated into new buildings at the design stage.

One important class of energy systems, for new or retrofit application, is the heat pump. Attention is being given to increasing the variety of heat pumps, improving their economics, and extending their application. Improved heat pumps are being developed in larger sizes for multiple-dwelling units or commercial buildings; for broader temperature ranges, to be economically applicable in different temperature zones of the country; and with alternative power drives such as gas engines. Currently, one problem with heat pumps in many areas is that, to be economic, they must be used in conjunction with central air conditioning.

Other developments, such as improved insulating materials and installation practices, are applicable to both new and retrofit markets. Improved space conditioning equipment may also be suitable for both markets. Other more elaborate energy-conserving space conditioning systems, such as integrated energy systems for single dwellings, apartments, or entire communities, are appropriate only for the new building market.

The simpler systems, applicable to existing buildings, can have significant near-term impacts, but the more elaborate systems will probably require 10-15 years for development and significant market penetration.

Industrial Sector

The industrial sector consumed, in 1976, 37 percent of all energy used in the United States. However, efficiencies in many industrial processes are low because the industrial complex evolved over a period of abundant and low-cost energy. Consequently, significant opportunities exist for development of new energy-efficient processes.

The ERDA industrial energy-conservation RD&D program has two thrusts: (1) toward the most energy-intensive processes of the six most energy-intensive industries — steel, chemicals/petroleum, glass, pulp and paper, cement, and food processing — which together use 70 percent of all industrial energy; and (2) toward the energy processes that are used across a wide spectrum of industries.

An important area under development, generally applicable to most industrial energy processes, is waste-heat recovery.

For example, the organic Rankine bottoming cycle, converts some of the waste heat from diesel- or gas-turbine power plants to mechanical and electric energy. A Rankine system using a pressurized organic working fluid, such as toluene, in a closed system will be demonstrated during the next five years. The hot exhaust (500°-1000° F) of a diesel- or gas-turbine engine converts the fluid to a vapor, which drives a turbine, thereby converting some of the waste-heat energy into mechanical and, possibly, electrical energy. The combination of diesel engine and Rankine bottoming cycle

may recover an additional eight percent of the initial fuel energy; a gas turbine bottoming cycle combination may save 15 percent.

Five 600-kilowatt (kw) organic Rankine bottoming cycle units will be field-tested in selected utility and industrial plants by 1980 under an ERDA contract. Other bottoming cycles have been developed to increase the efficiency of diesels and gas turbines used for industrial processes, for pumping gas and petroleum, and for propelling ships. Since they can be installed on existing diesels and gas turbines, these bottoming units may have a significant near-term impact.

One specific industrial activity not generally considered part of the conservation program is uranium enrichment. Introduction of the new gas centrifuge technology will save over 90 percent of the electric energy presently used in gaseous diffusion, as well as to enrich the uranium ore more efficiently. This will also contribute to significant energy savings through the end of this century.

Chapter 3

Technologies That Expand Existing Fuel Sources

Although energy conservation is a critical element in the National Energy Plan, additional energy supplies will also be required. Because of the long lead times needed to develop other sources and introduce new technologies, existing or imminent technologies that use present fuel sources must be stressed in the early 1980's. The Nation must concentrate on technologies that

- Produce additional petroleum and natural gas through enhanced recovery techniques;
- Expand the direct use of coal in both the utility and industry sectors;
- Expand the use of light water reactors in a once-through fuel cycle for electric power production.

In the late 1980's and beyond, these efforts can be augmented by:

- Expanding the use of coal through improved technologies for industrial use including conversion to synthetic fuel;
- Converting coal to electric power in an environmentally sound and more efficient manner;
- Developing advanced nuclear technologies consistent with nonproliferation objectives.

Descriptions of selected and illustrative technology approaches follow:

Produce Additional Petroleum and Natural Gas

Although the demand for petroleum and natural gas has risen, domestic capacity to meet that demand has not kept pace. Domestic petroleum, unrecovered from oil fields after conventional production, as well as natural gas, held in geologic formations considered currently unexploitable, could supply substantial additional quantities of energy in the near term and mid-term. For example, approximately 300 billion barrels of petroleum resources

are estimated to remain in existing, developed fields after conventional primary and secondary production. Obtaining these untapped supplies, however, requires enhanced recovery techniques for both petroleum and natural gas.

ERDA is sponsoring the development and testing of a variety of enhanced recovery techniques that will make a significant fraction of petroleum and natural gas resources available to the marketplace. Nineteen cost-shared field tests for enhanced oil recovery, using five available technologies have been initiated with industry. In addition, 18 jointly-funded natural gas stimulation projects are under way in seven states. The 13 contractors involved are working with three different technologies. In addition, new natural gas extraction technologies are being developed.

Direct Use of Coal

Coal will meet the greatest portion of increased U.S. energy needs. A comprehensive coal research and development program is, therefore, a high priority. The program will focus on meeting environmental requirements more effectively and economically, and will seek to expand the substitution of coal for petroleum and natural gas products.

Most of coal's impact in the short term (between now and 1985) should result from the expansion of existing technology used to burn coal directly. ERDA has a major effort focused on this task with the goal of developing economically attractive and environmentally sound techniques for burning coal, particularly higher sulfur coals. Success of this effort will accomplish two important objectives: it will increase the magnitude of the usable coal reserve; and it will reduce the costs involved (in many instances) by permitting greater use of eastern coals which are closer to the larger demand centers in the east.

The ERDA program has three generic approaches. One is to remove the sulfur (and other impurities) before combustion. Another is to develop new combustion techniques to burn higher sulfur coals in an environmentally sound manner. The third approach is to convert coal of varying quality to a clean synthetic fuel. Illustrative technologies needed to increase the use of coal by the industrial and utility sector are:

- Advanced cleaning or beneficiation methods (example of first approach)
- Atmospheric fluidized bed combustion (example of second approach)
- Low-Btu gasification (example of third approach).

Beneficiation, or cleaning, improves the environmental quality of mined coal to broaden its range of applications. The process involves the reduction of "free" sulfur and of rock, shales, and other "impurities" from the coal through grinding, washing, or floating. Beneficiated coal would be suitable for use in existing and future direct coal combustion technology.

Atmospheric fluidized bed combustion is a new system for burning coal efficiently, even in relatively small boilers, while controlling air pollutants. In this system, the coal is mixed with limestone and burned in a fluid bed. The limestone reacts with the sulfur in the coal, thereby effectively eliminating sulfur from the exhaust gas. Among others, problems with respect to coal and limestone feed, ash disposal, and sorbent regeneration systems for eliminating the large quantities of limestone or dolomite required for combustion are under investigation.

ERDA has begun operating a 30-megawatt steam boiler, using an atmospheric fluidized bed, at a power plant in Rivesville, West Virginia. A boiler of this size can produce about 300,000 pounds of steam per hour — an amount typical of an industrial boiler and about 3–5 percent of new utility boilers. In addition, a 200-megawatt demonstration unit is being considered for utility-industry operation; success at that stage would lead to commercial use in the mid-1980's.

More advanced fluidized bed systems, commercially applicable in the mid-term, are also being developed. These advanced units will be capable of operating in a combined cycle mode as part of a total community energy system. One such mode uses a high pressure fluidized bed system. The combustion products first pass through an advanced gas turbine, generating electricity, and then go through a conventional heat exchanger/boiler system, generating steam to run a turbine to generate more electricity. A final step would use the steam turbine exhaust to supply residential and commercial space heating services to the surrounding community.

In **low-Btu coal gasification**, coal is burned in a limited amount of air to produce a fuel gas with an energy content of 10 to 50 percent of natural gas. Because of this low-energy content, the gas cannot be economically stored or transported over long distances. Rather, it is intended for direct on-site use, either as a clean burning fuel or as a chemical feedstock.

Although low Btu coal gasification is potentially an environmentally acceptable use of coal, there are still some unresolved questions associated with the actual coal processing and conversion, particularly with respect to sulfur and trace elements in the coal, as well as the compounds produced during gasification.

Several demonstration projects, ranging from power generation in small generating units to the manufacture of hydrogen for chemical production, are planned or under way. Since this technology is evolving from existing systems and can be used in small-sized applications, it can be implemented in the near term.

In addition to the illustrative near-term technologies discussed above, there are other technologies with potential application in the longer term. Among these are magnetohydrodynamics, high Btu gasification, and technologies that produce synthetic crude oil from coal.

High Btu synthetic gas produced from coal may provide a substitute for declining natural gas supplies. The RD&D program for these technologies is focused on using advanced technologies. The technology for producing synthetic crude oil from coal is not as well developed as synthetic gas technologies. The RD&D program being pursued will include pilot plant demonstration of this technology.

Light Water Reactors

Light water reactors (LWR's) now in operation are generating about 10 percent of present electricity needs with an in-place capacity of about 46,000 megawatts electric (MWe). An additional 185,000 MWe are under construction or planned for introduction through the early 1990's. Thus, LWR technology with a once-through fuel cycle represents a current energy production capability that can play a significant part in the Nation's energy future, ease the demand on expansion of other fuel systems, and contribute to the reduction of U.S. petroleum imports.

Even though the necessary power plant technology is currently available, the streamlining of regulatory requirements will undoubtedly enhance the energy contribution of nuclear power while protecting public interests regarding health, safety, and the environment. Moreover, the full potential of nuclear energy will not be realized until problems with three closely related aspects of the fuel cycle are fully resolved. Namely,

- Assuring that peaceful uses of nuclear power will not contribute to the proliferation of nuclear weapons;
- Finding and providing sufficient fuel to expand nuclear capacity in an economically and environmentally acceptable manner;
- Disposing of wastes from nuclear facilities.

These problems are directly attacked by various elements of the President's comprehensive National Energy Plan and are discussed further below.

Effective safeguards systems require a balance of physical protection, material control, and material accountability. ERDA has research and development and operational activities under way in each of these areas to ensure that safeguards and security systems are technically and economically viable.

At the international level, in promoting measures to prevent the proliferation of nuclear weapons, the U.S. has:

- Taken a lead role in promoting the International Atomic Energy Agency (IAEA) safeguards and adherence by as many states as possible to those nuclear safeguards systems administered by that body;

- Agreed to place its facilities with no direct national security significance under IAEA safeguards;
- Strongly endorsed widespread adherence to the Nuclear Non-proliferation Treaty and favored the development of coordinated supplier state policies aimed at the development of common and prudent nuclear export policies;
- Judged that its nonproliferation influence would best be fostered through a program of carefully controlled nuclear cooperation rather than a posture of strict embargo. To this end, the U.S. has concluded approximately 33 nuclear cooperation agreements with 30 nations or international organizations designed to permit the export of U.S. reactors and fuels under effective bilateral and-IAEA controls.

There are still some differences of view among the industrialized nations as to how nonproliferation goals can best be fostered. In particular, the United States is pressing for a new international perspective as to how the LWR fuel cycle should be approached to assure that nonproliferation considerations receive highest priority.

In this regard, the Nation has opposed the spread of nationally controlled reprocessing and enrichment facilities, favoring a moratorium on the export of such technologies. Moreover, this country has raised fundamental new questions about the value of reprocessing and plutonium recycling in LWR's, and has argued that neither is necessary or inevitable for the U.S.

LWR's, as designed and operated today, require about 5,300 tons¹ of uranium oxide (U_3O_8 —commonly called "yellow cake") over a normal plant lifetime for each 1,000 MWe of capacity. Domestic uranium reserves² recoverable at a forward production cost of \$30³ per pound U_3O_8 are 680,000 tons U_3O_8 with another 140,000 tons U_3O_8 estimated to be available as a byproduct from phosphate and copper production. In addition to the reserves, ERDA estimates that there may be additional resources of 2,700,000 tons U_3O_8 potentially available. Of this potential, 1,090,000 tons are estimated to be in the probable category which, when combined with the reserves, form a base of over 1,800,000 tons U_3O_8 —sufficient to support all LWR's now operating or planned for the U.S. over their full operating lifetime. If the total combined reserves and potential resources are realized, they could support the lifetime requirement of over 600 nuclear reactors.

¹ Based on an average capacity factor of 61 percent, with 0.20 percent tails assay and a 30-year lifetime.

² Reserves are those resources which are estimated in known deposits by the evaluation of sample data on an engineering basis and from which production is reasonably assured with current technology.

³ Preliminary estimates indicate that an additional uranium resource of 200,000 tons U_3O_8 may be available at \$50 per pound U_3O_8 in sandstone-type deposits.

The extent to which nuclear power can contribute in the future will therefore be strongly affected by the rate at which potential resources are discovered and translated into reserves, and by the ability of the uranium mining and milling industry to expand to meet anticipated uranium production demands. It is currently estimated that a production rate of up to 60,000 tons U_3O_8 per year could be attained by the early 1990's, providing industry expands steadily in the interim period.

ERDA's National Uranium Assessment Program (NURE) will provide a more reliable estimate of the total uranium resource base and lead eventually to increased reserves. NURE is being redesigned to give greater attention to resource assessment and is also being expanded to acquire data on the thorium resource base.

In addition to expanding the resource base, energy production capability can be expanded in several ways. Alternate reactor concepts or LWR's which utilize less uranium per kilowatt hour of electricity produced can be developed. Therefore, emphasis is being given to advanced concepts other than the plutonium breeder. A second approach is to improve LWR technology for increasing capacity factors, and decreasing plant construction time and costs through standardization of designs. A third approach is to operate on the front end of the fuel cycle. If greater amounts of uranium 235 were extracted in the enrichment process than under current practices, less uranium ore would be required for each kilowatt hour of electricity produced in an LWR. All three approaches are being pursued.

In order to meet its domestic and worldwide obligations, the three presently operating U.S. uranium enrichment plants are currently being upgraded and U.S. enrichment capacity will be further expanded to provide an additional 8.8 million separative work units per year using a vastly improved and energy-efficient technology, centrifuge enrichment. This technology uses less than one-tenth the electric power needed for gaseous diffusion.

Government involvement in high-level waste management is unique since ERDA is required by law to accept and safely store high-level radioactive wastes generated by commercial operations. High-level radioactive wastes produced in the fission process present potential long-term hazards and need to be isolated from man's environment for extremely long periods of time. These wastes are contained in the spent fuel assemblies and can be stored or disposed of in that form. The basic approach to waste management is to place multiple barriers between radioactive wastes and man's environment. The current program objective is, by 1985, the development, construction, and operation of the first of a number of terminal storage facilities for the long-term, safe storage of radioactive wastes.

Chapter 4

Technologies That Use New Fuels

During the late 1980's and 1990's, conservation and the expanded use of existing supply sources will be the major complements to diminishing sources of petroleum and natural gas, but new fuels can and must be introduced into the market. Several technologies that use new fuels — shale oil, synthetic fuels from waste and biomass, geothermal heat, and solar energy — can have substantial impacts on the energy situation between 1985 and 2000.

Beyond 2000, the Nation will increasingly have to rely on energy systems based on "essentially inexhaustible" or renewable resources — e.g., solar electric, hot dry rock geothermal, or fusion. The status of some of the technologies that use new fuels is discussed below.

Shale Oil

Billions of barrels of oil may someday be recovered from shale deposits in the western states if environmental and economic problems can be overcome. Optimistic economic projections indicate that oil-from-shale could be produced profitably if priced at today's foreign crude petroleum prices. Major uncertainties, however, need to be resolved. Among them are: (1) the environmental impacts of shale oil production; (2) the availability of water (a scarce resource with other competing needs in oil shale regions); (3) the actual economics of shale oil production — e.g., the most developed technology, which involves mining shale and using heat to separate oil from crushed shale in a processing plant, appears to be the most costly; (4) inadequate knowledge of shale geology and characteristics; and (5) the attractiveness of the substantial initial investments required, since new technologies generally require higher investments per unit of net energy output. In spite of these uncertainties, shale oil could become an attractive new energy source for the U.S. and help to fill the liquid fuels demand-supply gap that may exist in the latter half of the century.

Past research by both government and industry has advanced surface retorting technology through the pilot plant stage of development. Pilot plant

testing of several alternative approaches is continuing using both surface and in-situ (or underground) processing techniques. In addition, several in-situ oil recovery contracts are anticipated shortly. Processes involving development of eastern shales are less well developed than those for western, but one major in-situ gasification project involving eastern shale is under way. If the economic problems can be resolved and the attendant environmental questions can be answered (e.g., on air pollution and water availability), shale oil technologies could begin to have an impact in the late 1980's.

Geothermal

Geothermal energy exists everywhere beneath the earth's crust, but in most places the heat is too diffused or too deep to be a potentially usable energy resource. National and regional surveys by the U.S. Geological Survey show that, in the U.S., potentially exploitable hydrothermal geothermal resources suitable for both electricity production and thermal applications are largely confined to the Rocky Mountain and western states. Recent data indicate areas of hydrothermal resources, suitable for moderate-temperature application, may also exist on the eastern seaboard. Geopressured geothermal resources are located principally in deep sediments along the Gulf Coast, and hot dry rock resources may underlie most of the country. Hydrothermal resources are more readily accessible and nearer development than the geopressured and hot dry rock resource bases. However, the latter resource bases are estimated to be much larger.

Current domestic efforts are focused on exploration and assessment of resources; on proving energy extraction and utilization technology and its economics; on resolving environmental concerns involving the release of toxic materials into the environment, subsidence, and waste water; and on reducing institutional barriers at all levels of government which tend to inhibit the use of geothermal energy. A federal loan guarantee program has also been implemented to make capital more available to the geothermal industry.

To stimulate the development of geothermal resources, the National Energy Plan proposes a tax reduction for intangible drilling costs, additional RD&D funds to evaluate the geopressured and liquid-dominated hydrothermal resources, and measures to streamline the leasing and environmental review procedures.

The geopressured resource base consists principally of hot brine and associated dissolved methane confined under pressure at considerable depths (5 to 15,000 feet) by deep impermeable rocks. Serious environmental problems must be resolved to tap this energy resource. First, withdrawal of the hot brine may produce subsidence as reservoir pressure is decreased, unless appropriate control measures, such as brine reinjection, are taken. Second, the quantities of air pollutants that may be released are not known. Third, where a fresh water aquifer occurs above a geothermal reservoir, the fresh water could be contaminated by the brine released. Nevertheless, geopressured resources

are of particular interest because of the magnitude of the potentially recoverable energy (about 2,500 quads) which is thought to include significant amounts of dissolved methane gas. This potential warrants major efforts to refine knowledge of the actual magnitude and content of the reservoirs, to develop the technology to drill economically at great depths, and to reduce the technological and economic uncertainties concerning reservoir producibility and longevity.

For the longer term, hot dry rock offers an even larger potential renewable resource option to provide substantial quantities of high grade energy. Rock deep in the earth contains vast quantities of heat, but little or no fluid to bring the heat to the surface. Therefore, introduction and circulation of a heat transfer fluid, such as water, are required to extract usable energy. However, the economic costs and technical difficulties of drilling to such depths and recovering such highly heated fluids or other transfer mechanism without undesirable environmental impact suggest that this resource is unlikely to enter the market in a significant way until the next century. ERDA is determining the characteristics of the resource and developing techniques for heat extraction and reservoir stimulation. Experiments are being pursued at Fenton Hill, New Mexico, to evaluate heat extraction and reservoir stimulation concepts.

Solar Heating and Cooling

The sun is an inexhaustible source of energy. Growing public interest is evidenced by some 200 installations of solar heating systems in 1975 and an estimated 1,000 or more systems in 1976. The Federal Government subsidized about one of every seven of these installations. There are now an estimated 500 companies offering solar systems and components on a commercial basis. The President's National Energy Plan calls for tax credits for solar installations and the use of solar heating in 2.5 million homes by 1985.

The primary R&D objective is to develop and demonstrate economically competitive systems with a wide range of applications. Current R&D efforts are aimed at perfecting key components — collectors, storage and heat exchanger units, heat pumps and air conditioners, and appropriate controls for the systems. A large-scale program to demonstrate residential and commercial solar heating systems is also under way. These efforts should permit widespread introduction of solar hot water systems¹ and solar space heating in the late 1970's and early 1980's. Increased market penetration depends on further reducing per-unit costs, improving system performance, and removing institutional barriers.

Similar efforts are under way to apply solar heating in agricultural and industrial situations in which large quantities of low-temperature heat are

¹ For a variety of applications, these systems are already economically competitive in some areas of the country.

required. It is estimated that over 40 percent of the industrial and nearly all of the agricultural heat needed at the point of application and for pre-heating is below 400° F. Solar energy technology is already available for producing hot water, hot air, or saturated steam to meet these requirements, and a number of ERDA-sponsored projects are under construction to demonstrate such processes as crop and grain drying, the heating of animal shelters and greenhouses, the production of hot water for commercial textile dyeing operations, and the curing of concrete blocks. Solar production of agricultural and industrial process heat should be competitive with conventional energy sources in some areas of the country in the near future.

Energy from Waste and Biomass

A variety of readily available resources — municipal waste, sewage sludge, agricultural and forest products, and animal residues — can be burned directly or converted to synthetic liquid and gaseous fuels. In addition, some of the resulting synthetics may be valuable as petrochemical feedstocks such as methane, hydrogen, and ammonia. The technologies used for conversion can therefore be viewed as a means of controlling pollution and conserving energy as well as of producing new fuels.

Biomass, which includes animal manure as well as agricultural and forest crops and their residues, and aquatic plants such as algae and kelp, can be converted by a series of processes into clean fuels and other energy-intensive products. Methane, for example, can be produced from animal manure by anaerobic digestion, and then upgraded to pipeline-quality Substitute Natural Gas (SNG). Cellulosic biomass such as wood or sugar cane can be broken down into sugars which, when fermented, yield ethanol, a liquid which can be used as a gasoline extender in an unmodified internal combustion engine. Gasification of biomass in a manner analogous to the thermal reactions of petroleum refining can produce gaseous fuels or a synthesis gas which can be transformed into methanol, SNG, hydrogen or ammonia. Some forms of biomass can also be burned directly to produce heat for a variety of uses.

In the long run, both terrestrial and aquatic biomass may be purposefully grown (energy farming) for conversion to fuels, with wood being a large source of the biomass. Questions concerning the economics of production, collection and transportation of biomass to a conversion facility, biomass availability, competing uses of land, and potential environmental impacts must be answered before fuels from biomass can make a major impact on the national energy problem.

Solar Electric Systems

Various technologies — photovoltaics, thermal electric, wind, and ocean thermal — are part of the technology category, solar electric. Solar power is a

renewable energy source and is relatively free from the pollution concerns that face other energy supply systems.

Most of these technologies have already been demonstrated. Nevertheless, it is difficult to predict when these systems will become marketable. The problem is one of engineering design and development to provide economically competitive systems. However, some of these systems may find initial application in small, specialized markets in which higher costs are acceptable. Such systems might also find long-term applications as decentralized energy sources.

Photovoltaic, or solar, cells have been used in the space program for some time and are commercially available. A federal RD&D program is also under way to help reduce the current cost of solar arrays by a factor of 30 by the mid-1980's — that is, from about \$15 per peak watt of output at present to about 50 cents per peak watt by 1986. Initial domestic residential/commercial use of such solar systems is expected to occur in the mid-1980's, but widespread use will depend on additional cost reductions — i.e., to 20 cents per peak watt by the 1990's. This latter advance may require introduction of new cell materials or other configurations that offer higher cost reductions. There seem to be a variety of uses abroad that may be economically competitive now.

Thermal electric conversion systems use concentrated solar energy to heat water or other working fluids to power turbines, which, in turn, drive electric generators. Such systems can also be incorporated into total energy systems that supply heat for industrial processes or space heating and cooling as well.

Large tracking mirrors (heliostats) can focus large quantities of solar energy on central receiver systems — boiling a working fluid and producing steam to power electric generating equipment. Commercialization of this technology depends on development of an economical system for concentrating the sun's energy. System costs must be reduced by a factor of 5 to 10 if such systems are to be used widely in intermediate-load situations.

Various experimental units are being built, including a 5-megawatt thermal test facility in Albuquerque, New Mexico. A 1-megawatt thermal receiver was recently built and tested in the French solar facility; a site near Barstow, California, has been selected for a 10-megawatt pilot plant, and development of more economic heliostats is under way. The first pilot plant produced 35 kilowatts of electric power in April 1976.

Local heat rejection, potential negative effects of shadowing large areas of land and competing alternate uses for land areas are other issues needing resolution prior to large-scale commercialization.

Wind energy conversion systems are more modern and economic versions of the old-fashioned windmill. Several projects are under way to help bring about development of more cost competitive wind energy systems. A 100-kilowatt system has been constructed and tested for over a year as a

cooperative ERDA/NASA project. The first of two 200-kilowatt experimental machines is being fabricated for installation at Clayton, New Mexico, and a 1.5-Mw experimental system design is under way. In addition, smaller wind systems for decentralized applications are being developed and have the potential for early commercialization of wind energy technologies. To achieve market penetration for this technology, the economics must be improved by a factor of 2 to 4, and questions concerning controls, structural dynamics, site characteristics, television interference, and the service life of large rotors must be resolved.

Ocean Thermal electric conversion systems utilize the enormous, but diffuse, quantities of heat collected and stored in the oceans to generate electricity. Ocean thermal systems use warm surface water to heat a secondary system liquid, such as ammonia, causing it to vaporize and turn a turbine connected to a generator. Cold water from the ocean depths condenses the ammonia vapor, and the cycle is repeated.

Such systems might provide electricity for mainland distribution or for energy-intensive processes, such as manufacturing ammonia or processing aluminum ore, at sea or on island sites. Although small units have been operated, the cost of current technology is such that major cost reductions and performance improvements are required before commercialization can be contemplated. Technical problems include producing an efficient heat exchanger, controlling its biofouling and corrosion, and constructing and positioning large, seagoing platforms. In addition, a variety of socioeconomic, institutional, and environmental questions have to be answered since these systems are still in the early developmental stages.

Experimental studies for heat exchangers and biofouling control technologies are under way, and critical component testing will begin in Fiscal Year (FY) 1977.

Advanced Nuclear Reactors

The United States is currently reorienting its advanced nuclear reactor research and development program due to concern with proliferation dangers associated with the plutonium fuel cycle. The President has proposed to defer efforts to commercialize the Liquid Metal Fast Breeder Reactor (LMFBR). He has proposed that the systems design for the Clinch River Breeder Reactor Demonstration (CRBR) plant be completed, but construction and operation be cancelled. However, the Fast Flux Test reactor facility under construction at Hanford will be completed and become operable by 1980.

Alternative reactor systems, including breeders and advanced converters, will be investigated with emphasis on nonproliferation and safety factors. Spectral shift and tandem cycle techniques are being considered as methods to improve the performance of converter reactors. Coprocessing of spent fuel from converter reactors is being examined as a possible method for increasing

fuel supply to converter reactors or breeder reactors while reducing proliferation dangers. A variety of thorium breeders as well as converter reactors are under consideration as alternatives to the LMFBR. The fuel cycle alternative studies will be completed within about two years.

Fusion

Although fusion technology is still decades away from commercial market introduction, a strong incentive for developing fusion is that its fuel is available in virtually unlimited amounts and at negligible cost.

The present program for developing fusion involves two very different approaches. The first, magnetic confinement, involves the confinement and heating of a "plasma" consisting of deuterium and tritium to a point at which the high velocity nuclei fuse on collision. The first experimental test facility designed to produce significant thermonuclear energy is under construction at Princeton. Development programs are now in place in all fusion technology problem areas: materials, plasma heating, fueling, magnets, impurities, vacuums, tritium handling, maintenance, energy storage and transfer, and power density.

The second approach to developing fusion, namely inertial confinement, involves the use of laser, electron-beam, and ion-beam sources to implode pellets of deuterium and tritium, resulting in fusion of the nuclei and release of energy. A major laser facility is expected to demonstrate high energy gain from pellets in the 1980's, thus establishing the scientific feasibility of net energy production from an operating device.

Although the major objective of both fusion approaches is to develop commercially viable electric power reactors and although the inertial confinement fusion program has significant weapons technology applications, other possible applications are being considered. Among these are direct production of hydrogen gas and/or synthetic fuels, chemical and material processing, fissile fuel production, fusion/fission hybrid reactors, and auxiliary use of reactor heat.

Most of the long-term technologies described above are the subject of a comprehensive strategic study which is discussed in Chapter 6.

Chapter 5

Development of Support Technologies

In addition to specific RD&D efforts in energy conservation and supply technologies, various broad-based support programs and activities — basic research, data collection and dissemination, education, and training — are a vital part of the national energy RD&D effort. The magnitude, scope, and number of these supporting activities make it impractical to present a comprehensive review in this report. However, two areas — basic energy research, and environmental and safety research — are indicative of the efforts needed to support a national energy RD&D program.

Basic Energy Research

The market-oriented technology programs concentrate their efforts on developing energy-related concepts, processes, and systems to the point of practical use. These efforts are not enough, however, if the long-range welfare of the Nation is to be assured. The applied programs must be complemented with one that is more basic in its approach, and asks its questions from the viewpoint: What will Nature permit? What new knowledge is needed to improve existing processes? How can current approaches be made obsolete?

This long-range program must focus the scientific talent of the Nation on selected areas where the need is greatest. Most important of all, it must enlist the most creative minds in choosing those general areas and topics where significant progress is most likely. Only through such innovative research will major, new technological advances be possible.

ERDA, as the federal agency primarily responsible for developing energy technology, has a correspondingly great responsibility for conducting a vigorous and diversified program of research in sciences related to the production and efficient use of energy.

The benefits of this program are several. Its focus on the more basic level often results in understanding that is applicable to several of the technology programs. Its scientific viewpoint often creates radically new and different approaches to existing problems. Its utilization of the educational resources of

the Nation assists in the production of the next generation of trained scientific talent. Finally, the products of this research are useful to all: government, industry, and the small innovator.

Environment and Safety Research

The spectrum of energy technologies needed to solve the Nation's energy problem must be not only economically attractive but also environmentally and socially acceptable to consumers and the public at large. To ensure that this goal is met, an environmental research program is needed to:

- Identify and characterize the environmental, health, and safety issues and public concerns associated with the commercial operation of specific energy systems;
- Establish standards of environmental and safety performance for each technology being developed to reduce the severity of environmental and health impacts and the costs of their control;
- Identify environmental control requirements;
- Interact with the public, private organizations, and other governmental agencies to ensure awareness of public concerns about energy developments and environmental and safety research, as well as to disseminate information to the public on environmental problems and progress;
- Ensure that all ERDA-controlled activities minimize risks to the safety of the public and adequately protect property and the environment.

Many organizations, both government and private, must be part of an overall, national effort to provide this research. In carrying out its part of this responsibility, ERDA applies several important guidelines:

- Environmental and safety performance is an integral part of energy technology performance and has high priority within each technology program.
- Protection of the health and safety of workers and of the general public from potentially adverse impacts of energy development and use is a basic performance standard for all energy technologies.
- In compliance with the spirit of the National Environmental Policy Act (Public Law 91-190), detailed environmental planning is an essential part of every program plan. In addition, an environment and safety overview of agency-wide activities will assess changes in funding priorities, scheduling, and health and environmental performance goals.

- Public involvement programs and environmental and safety RD&D coordination activities at both the agency and the technical program level seek to: (1) keep technical and policy decisionmakers informed about related external activities, perceptions, and problems; (2) coordinate environmental and safety activities effectively; and (3) provide all interested groups with a realistic view of ERDA's and the Nation's environmental and safety progress and problems related to energy.

To embody these philosophical guidelines in all energy programs, environmental and safety considerations must be included not only in demonstration plants but also in all experimental and pilot operations.

In addition, environmental development plans (EDP's) will be developed for major technology programs. EDP's will provide a guide for planning and managing environmental, health, and safety activities required by technology development programs, including identification of environmental issues, plans for solutions, and key milestones for environmental impact assessments and environmental impact statements. The initial cycle of EDP preparation for the major technologies is scheduled for completion by the fall of 1977.

Chapter 6

On-Going Program Planning Studies

Future budgets will reflect the results of two major ERDA-wide studies now under way, the Market-Oriented Program Planning Study and the Inexhaustible Energy Resources Study. These studies will serve as the basis for an effective federal research, development, and demonstration program as described in the President's National Energy Plan:

"An effective Federal research, development, and demonstration (RD&D) program is indispensable for the production of new energy sources. Research is not an end in itself. The purpose of RD&D is to produce technologies for practical use. The final stage of a successful RD&D program is commercialization, the movement of a functioning technology into the marketplace.

"... the groundwork for eventual commercialization should generally be laid during the RD&D stage. Before embarking on costly research projects, the Government should have the best possible information on prospects for economic success and institutional acceptance. As scientific and technical advances are made, economic and institutional barriers to commercialization should also be addressed, so that if technical success is achieved in the RD&D program, commercialization can take place rapidly."

Market-Oriented Program Planning Study

No matter how ingenious a new energy system may be or how great its theoretical promise, success — or lack of it — is ultimately judged in the commercial sector. In recognition of this crucially important fact, ERDA's Fiscal Year 1979 planning and budgeting activities include a Market-Oriented Program Planning Study, or MOPPS. Its purpose is first to examine the markets likely to be served by new and existing technologies and then to determine which of them best accommodate which markets and at what costs (both absolute and relative to competing fuel systems). This assessment should then help make it possible to determine the rate at which individual technologies

can achieve market penetration. RD&D leadtimes can then more realistically be established for the technologies under investigation.

Within the broad objective of coupling R&D thrusts to the market-place rather than to the energy resource as commonly practiced, the MOPPS study seeks to:

- Classify candidate near and mid-term technologies into **key**, **uncertain**, and **hedge** categories related to the likely role of the technology in future energy systems and thus to the appropriate objectives, priority, and pace of the RD&D program;
- Establish specific goals for each such major technology against which progress can be measured;
- Provide the basis for a reassessment of ERDA's program strategies and goals;
- Highlight budget issues as to the rate of development of major technologies, the level of redundancy necessary to cover technological risk, and the need for technological hedges.

The current phase of MOPPS is scheduled to be completed by the end of July, 1977, and will assist in highlighting budget and planning issues to be resolved by ERDA program planning prior to the completion of the FY 1979 budget during the fall and winter of 1977.

Inexhaustible Energy Resources Study

The Inexhaustible Energy Resources Study is directed at developing an RD&D strategy for technologies that are based on renewable or essentially inexhaustible resources. Because most of these technologies tend to be among the longer-term options, a MOPPS-type analysis, with emphasis on near-term market trends, is not applicable. Instead, the study is oriented towards answering the questions of how soon the technologies that exploit renewable or essentially inexhaustible resources will be needed, and what mix of technologies should be deployed to meet those needs. Conceptually, the time window is bounded at one end by the "earliest feasible" date for completion of a successful RD&D program and at the other end by the "latest permissible" date at which the "need" for such technology could become critical.

The RD&D strategy that will result from the study will be used as a guide in formulating ERDA budget requests for the various renewable or essentially inexhaustible options. Such requests can be viewed in two ways: (1) the total RD&D budget on all the options, and (2) the relative balance between subprograms, i.e., the fraction of the total for photovoltaics, solar heating and cooling, fusion, breeder reactors, etc.

Among the questions that the study is addressing are:

- What are the alternative paths to the utilization of inexhaustible

or renewable resources in terms of primary resources (the sun, the earth's heat, deuterium and lithium, uranium 238, etc.)?

- At what pace should the Nation begin to deploy energy systems based upon inexhaustible resources?
- What major decision points are necessary and/or desirable?
- What are the cost-benefits of accelerating or decelerating sub-programs to allow for broader, more far-reaching decisions?
- When can or should go/no-go decisions be made?
- What funds are required to make choices at an earlier or later date?

The study will extend in time past the completion of the FY 1979 budget but it is anticipated that some initial insights may be achieved which will be helpful in the formulation of that budget.

Chapter 7

Overview of ERDA's Budget¹

The President's FY 1978 budget request to Congress for all activities of the Energy Research and Development Administration totals \$7.3 billion in budget authority and \$6.3 billion in budget outlays. Of this amount, \$3.8 billion in authority and \$3.1 billion in outlays are directly associated with energy RD&D. The total budget is allocated as shown in Table I.

This ERDA budget overview focuses on decisions related to the energy RD&D portion of the budget for nonnuclear and nuclear RD&D activities and discusses the trends in the development of that budget since FY 1976.

Energy RD&D Budget Nonnuclear Initiatives

Recognizing the importance of a strong technology program, President Carter made major revisions to the ERDA budget request in February (Table II). Increased authority of \$247 million was requested for near-term effort on conservation, fossil, and solar heating and cooling. Funding for these new emphases was provided primarily from reductions in long-term programs such as the nuclear breeder, fusion, and solar electric applications.

In line with this initial shift in emphasis, the President requested further budget increases for key nonnuclear ERDA programs in April, coincident with the publication of his National Energy Plan. The emphasis in the current revision was on small-scale energy systems in the solar and geothermal categories (\$28 million) with further increases for fossil (\$17 million) and conservation (\$7 million). Funding for these further emphases was provided primarily from reductions and adjustments in the nuclear program of \$183 million.

¹ Includes the February and the April budget changes initiated by President Carter.

Table I
ERDA'S FY 1978 BUDGET REQUEST
(\$ in Millions)

| | <u>Budget Authority</u> | <u>Budget Outlays</u> |
|-----------------------------------------------|-----------------------------|---------------------------|
| Energy Research Development and Demonstration | 3,790 | 3,079 |
| Basic Research and Technology Development | 672 | 636 |
| Uranium Enrichment Activities (Revenues) | 1,361 (966) | 1,315 (966) |
| National Security | 2,139 | 1,915 |
| Program Management and Support | 309 | 310 |
| | <hr/> | <hr/> |
| Total | <u>\$7,305</u> | <u>\$6,289</u> |

Table II
FY 1978 Energy Budget
(Budget Authority — \$ in Millions)

| | <u>Past Adminis- tration Budget January 1977</u> | <u>New Adminis- tration Budget Revision February 1977</u> | <u>New Adminis- tration Budget Revision April 1977</u> |
|----------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Conservation | \$ 158 | \$ 318 | \$ 325 |
| Fossil Energy | 598 | 640 | 657 |
| Light Water Reactors | 642 | 617 | 548 |
| Solar Heating and Cooling | 45 | 90 | 96 |
| Solar Electric and Other | 260 | 215 | 224 |
| Geothermal Energy | 88 | 88 | 101 |
| Fusion | 513 | 433 | 433 |
| Advanced Reactor & Fuel Cycle Concepts | 998 | 799 | 685 |
| | <hr/> | <hr/> | <hr/> |
| Total | <u>\$3,302</u> | <u>\$3,200</u> | <u>\$3,069</u> |

Some of the key initiatives in the total FY 1978 budget request as compared to FY 1977 can be summarized on a program-by-program basis as follows:

- **Conservation** — Increases are provided for efforts to develop efficient and fuel-flexible heat engines for transportation, to improve energy conversion efficiency, and to support the Electric and Hybrid Vehicle Act and a pilot energy extension service program. To help conserve natural gas, programs for development of small fuel cells and gas-fired heat pumps are being accelerated. Studies will be conducted aimed at the recovery of waste heat from ERDA's present enrichment plants and production reactors for use both in its own facilities and for supply to nearby external users, thus emphasizing the Federal Government's own commitment to waste heat utilization.
- **Fossil Energy** — Increases are provided for programs to substitute coal and coal-derived fuels for oil and gas and improve techniques for recovery of petroleum and shale oil resources. Design for a solvent refined coal demonstration plant will be initiated. Development of gas extraction from eastern shales will be accelerated. Possible environmental problems of carbon dioxide production from fossil fuel combustion will be studied.
- **Solar Energy** — Funding allows continued implementation of the solar heating and cooling demonstration program. Additional R&D effort associated with solar heating, high temperature collectors and solar space cooling will be pursued. Increases are provided to expand agricultural and industrial process heat and biomass applications and support to solar electric R&D activities. Specific efforts will be made to expand engineering design efforts on photovoltaic systems with concentrators and to pursue additional development of small wind machines for remote locations.
- **Geothermal Energy** — Increases are provided to intensify resource exploration, assessment, and utilization and to initiate a 50-megawatt geothermal demonstration power facility. Characterization of geopressed resources and non-electric applications of geothermal energy will be accelerated.
- **Fusion Power** — The budget provides for continued work on magnetic confinement alternatives and construction of the Tokamak Fusion Test Reactor at Princeton, New Jersey, and for expanded work in laser fusion on laser development and target experiments.

Energy RD&D Budget Nuclear Initiatives

The appropriate role of nuclear power and the concerns associated with the proliferation of nuclear weapons has been a major consideration for the Administration. Since the Administration took office, extensive reviews have taken place and a number of policy decisions have been reached.

The United States has a technology — the existing light water reactor (LWR) with a once-through fuel cycle — on which it can depend today for nuclear power with minimum risks.

The President has indicated in his National Energy Plan that the United States intends to use the LWR to help meet today's energy needs and to give increased attention to the production of uranium fuels for LWR's, LWR safety, licensing, and waste management. This policy will permit nuclear power to be used safely to meet U.S. energy demands for many decades. In seeking advanced nuclear technologies, the Nation must minimize the risk of nuclear proliferation, but with the knowledge that no advanced nuclear technology is wholly benign in this regard. Thus, the President announced on April 7 that the United States will defer indefinitely commercial reprocessing and recycling of plutonium. ERDA's nuclear research program is being reoriented to study alternative reactor and fuel cycle technologies.

The budgetary consequences of these changes in the nuclear program are shown in detail on Table III.

ERDA is also reorienting, within existing budgets, its National Uranium Resources Assessment Evaluation program to focus more sharply on a timely evaluation of the ultimately available domestic resources of uranium.

The President has proposed that construction of the Clinch River Breeder Reactor (CRBR) project be indefinitely deferred. The Breeder Program funding would be reduced, but a base program would be maintained. Efforts would now be directed towards evaluation of alternative breeders with emphasis on nonproliferation and safety concerns. A number of the breeder program support facilities previously planned would be delayed in light of the program reexamination. However, the Fast Flux Test Facility at Hanford, Washington, would be completed and used for fuel studies needed by the program.

The proposed reoriented LWR Fuel Cycle activity would be redirected to develop Advanced Fuel Cycles for alternative reactor concepts with enhanced nonproliferation characteristics and expanded work on thorium fuel cycles. Supporting nuclear energy assessment activities would be increased for more detailed study of alternative total reactor systems (including advanced converters) and other concepts to enhance proliferation resistance.

Recognizing the legitimate aspirations for the benefits of nuclear power on the part of many nations of the world, ERDA will reopen the order book for provision of enrichment services both at home and abroad from U.S. Government capacity. Such fuel services will be assured to any country that shares U.S. nonproliferation objectives and can accept certain conditions consistent with those objectives.

Table III
FY 1978 Fission Budget
(Budget Authority — \$ in Millions)

| | Past Adminis- tration Budget January 1977 | New Adminis- tration Budget Revision February 1977 | New Adminis- tration Budget Revision April 1977 |
|------------------------------------|----------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------------------------------|
| <u>Light Water Reactors</u> | | | |
| Fuel | \$ 369 | \$ 344 | \$ 248 |
| Technology & Safety | 98 | 98 | 104 |
| Waste Management | 175 | 175 | 195 |
| Subtotal LWR | <u>\$ 642</u> | <u>\$ 617</u> | <u>\$ 547</u> |
| <u>Advanced Concepts</u> | | | |
| LMFBR Base Program | 620 | 506 | 450 |
| CRBR | 235 | 150 | 33 |
| Other Advanced Reactor Concepts | 75 | 75 | 75 |
| Advanced Fuel Cycle Concepts | 52 | 52 | 104 |
| Nuclear Energy Assessments | 16 | 16 | 23 |
| Subtotal Advanced Concepts | <u>\$ 998</u> | <u>\$ 799</u> | <u>\$ 685</u> |
| Total LWR & Advanced Concepts | <u><u>\$1,640</u></u> | <u><u>\$1,416</u></u> | <u><u>\$1,232</u></u> |
| <u>Uranium Enrichment</u> | | | |
| Enrichment | \$1,685 | \$1,685 | \$1,361 |

The expansion of U.S. enrichment capacity had previously been planned to occur using the historic gaseous diffusion technology. A vastly improved and energy efficient technology (using less than one-tenth of the electric power), namely centrifuge enrichment, has now reached the stage of development where it is suitable for application. It is this newer and less energy-wasteful technology which ERDA will now employ for expanded government capacity.

Budget Trends

Excluding uranium enrichment and supporting programs, ERDA's energy budget has radically changed in dollar and program distribution between FY 1976, the first full-year ERDA budget, and today's revised FY 1978 budget (Table IV).

Conservation and renewable technologies, starting from low levels in 1976, have increased by factors of about 3 and 2 respectively.

Table IV
ERDA Energy Programs
(Budget Authority — \$ in Millions)

| Program | FY 1976 | FY 1978 Budget January 1977 | FY 1978 Revision February 1977 | FY 1978 National Energy Plan April 1977 ¹ | Increase in FY 1978 (April revision) over FY 1976 | |
|---------------------|------------|-----------------------------------------|--------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------|-----------------|
| | | | | | \$ Millions | % In- crease |
| Conservation | 76 | 158 | 318 | 325 | 249 | 328 |
| Fossil | 426 | 598 | 640 | 657 | 231 | 54 |
| Renewables | 146 | 393 | 393 | 421 | 275 | 188 |
| Light Water Reactor | 153 | 642 | 617 | 548 | 395 | 158 |
| Advanced Concepts | 602 | 998 | 799 | 685 | 83 | 14 |
| Fusion | 246 | 513 | 433 | 433 | 187 | 76 |
| Total | 1,649 | 3,302 | 3,200 | 3,069 | 1,420 | 86% |

¹ Does not include \$1.0 million for carbon dioxide study programs and \$5.0 million for international efforts to assist less developed countries.

Light water reactor work, also starting from a low level, first expanded significantly, but (with current decisions to defer chemical reprocessing) has been reduced, showing an overall growth factor of about 1.5.

• Fossil efforts, starting from a higher initial level in 1976, have increased by 54 percent.

In the long-term programs, fusion has grown at about 75 percent, and advanced nuclear concepts first showed large increases but (with current decisions to defer the CRBR and to study alternatives) has been reduced, showing an overall increase of about 15 percent.

In the ERDA FY 1978 budget, as revised to reflect the emphases of the President's National Energy Plan, conservation and renewables together represent about 25 percent of the energy budget; fossil, light water reactors, and advanced nuclear concepts represent about 20 percent each; and fusion represents the remaining 15 percent.

As noted in the President's National Energy Plan:

"A balanced RD&D program should have near-term as well as long-term benefits, should promote conservation and nonconventional resources as well as conventional resources, should support small-scale as well as large-scale projects, and should enlist the talents of individual inventors and small business as well as major corporations. In its revisions of the fiscal year 1978 budget, the Administration began the process of reorienting RD&D priorities to meet the country's real needs."

The President's overall energy plan provides the needed context for the National Energy RD&D effort. ERDA's activities in this area, combined with those of other federal agencies involved in energy RD&D, can provide the basis for technological change needed to allow the United States to weather a major transition in energy supplies and successfully meet the energy needs of the future.